University Observatory, Oxford; Potsdam Observatory, Photographische Himmelskarte, Band 4, presented by the Observatory; Dr Backlund's Reports on the Russian Mission for the measurement of an Arc of Meridian in Spitzbergen, presented by the Pulkowa Observatory.

Twenty charts of the Astrographic Chart of the heavens, presented by the Royal Observatory, Greenwich; six positive enlargements on glass of photographs of portions of the Solar Surface, taken at the Royal Observatory, Greenwich, and photograph of the Solar Eclipse of 1905 August, taken at Sfax, Tunis, presented by the Astronomer Royal; nine photographs of Mount Wilson Observatory, and photographs of the Spectra of Sun-spots, presented by Prof. G. E. Hale.

On the Inclinations of Binary Star Orbits to the Galaxy.

By T. Lewis and H. H. Turner.

Summary.

§ 1. It was suggested that the axes of rotation of variable stars tend to be parallel to the Galaxy. Do double stars tend to revolve in corresponding fashion?

§ 2. List of 59 orbits.

§§ 3–5. Application of method used for variables: with the result that orbits nearly at right angles to the line of sight seem to avoid the Galactic Poles, as was noticed for stars which present their poles to us.

§§ 6–12. Discussion of distribution of the spurious poles of double-star orbits, and conclusion that at least 75 per cent. are scattered uniformly over the sphere.

§ 13. If they were uniformly scattered there would remain $38\frac{1}{2}$ real poles within 30° of the Galaxy and $20\frac{1}{2}$ in the rest of the sphere: whereas, on the hypothesis of uniform distribution, both numbers should be $29\frac{1}{2}$.

§ 14. If the small orbits ($a<0''\cdot5$) be excluded, there are 33 poles within 30° of the Galaxy as against 15 in the remainder of the sphere.

§§ 15–16. There is evidence of systematic error in very small distances, which would specially affect small orbits.

§ 17. If orbits of large eccentricity be excluded ($e>0\cdot51$) there remain 21 poles within 30° of the Galaxy, and 5 in the rest of the sphere.

§§ 18 and 19. Remarks on high eccentricities.

1. In a paper by one of the present writers on the "Classification of Long-period Variables" (*Mon. Not.*, lxvii. p. 332), it was suggested that the type of light curve might indicate the inclination of the axis of rotation of the star to the line of sight; and attention was drawn to the fact that, in terms of this hypothesis, there were no variables near the poles of the Milky Way with their axes turned towards us. After the meeting at which the above paper was read, Mr Inwards suggested that the orbits of double stars might show a similar peculiarity of distribution. Various attempts have already been made to detect any such peculiarity, without success; see, for example, pp. 244–6 of Dr T. J. J. See's *Evolution of Stellar Systems*, and Miss Everett's paper in *Mon. Not.*, lvi. pp. 464–5. On examining these lists, it will be seen that there is no very well-marked feature of distribution; but at the same time there appear to be certain tendencies which have perhaps not yet received sufficient attention, and the following notes may serve to promote further inquiry.

2. There were some discrepancies in the two lists above mentioned; and other orbits have since been computed. Hence the first step was to form a revised list of orbits as follows:—

TABLE I.

List of 59 Orbits in Order of R.A. of Star.

No.	Name.	R.A.	Dec.	Gal. Lat.	e	a	i	Γ	Γ
		h. m.	°	°		″	°	°	°
1	Σ 3062	0 1	+58	− 4	0·45	1·37	44	64	51
2	Σ 2	0 4	+79	+16	·40	0·55	70	84	81
3	13 Ceti	0 30	− 4	−67	·74	0·21	48	69	30
4	β 395	0 32	−25	−87	·15	0·66	77	78	56
5	η Cassiop.	0 43	+57	− 6	·34	8·51	43	67	54
6	36 Androm.	0 50	+23	−40	·75	1·01	45	87	10
7	Σ 186	1 51	+ 1	−57	·67	1·15	74	84	78
8	γ^2 Androm.	1 58	+42	−19	·82	0·35	77	83	33
9	Σ 228	2 8	+47	−13	·38	0·90	66	66	49
10	20 Persei	2 48	+39	−19	·48	0·24	74	38	14
11	40 Eridani	4 11	− 8	−37	·14	6·25	69	60	18
12	β 883	4 46	+11	−20	·48	0·24	28	79	66
13	Sirius	6 40	−17	− 8	·59	7·59	45	78	66
14	9 Argus	7 41	−14	+ 8	·70	0·65	78	57	53
15	ζ Cancri	8 6	+18	+26	·38	0·86	11	67	62
16	ε Hydræ	8 41	+ 7	+38	·68	0·24	36	89	41
17	Σ 3121	9 12	+29	+44	·33	0·67	75	67	62

TABLE I.—*continued.*

No.	Name.	R.A. h. m.	Dec. °	Gal. Lat. °	e	a ″	i °	Γ °	Γ′ °
18	ω Leonis	9 23	+ 9	+40	·54	0·88	63	67	14
19	φ Ursæ Maj.	9 45	+55	+48	·44	0·34	30	64	26
20	ξ Ursæ Maj.	11 13	+31	+70	·40	2·51	56	59	57
21	ι Leonis	11 19	+11	+64	·76	2·49	66	71	65
22	OΣ 234	11 25	+42	+68	·30	0·35	51	65	42
23	OΣ 235	11 27	+62	+53	·32	0·87	49	89	19
24	Σ 1639	12 20	+26	+86	·70	0·71	58	61	55
25	γ Centauri	12 36	−48	+14	·80	1·02	62	86	81
26	γ Virginis	12 37	− 1	+62	·88	3·90	30	43	36
27	42 Comæ	13 5	+18	+82	·48	0·66	90	83	83
28	OΣ 269	13 28	+36	+77	·36	0·32	71	69	61
29	25 Can. Ven.	13 33	+37	+75	·87	1·12	36	43	26
30	β 612	13 35	+11	+70	·27	0·31	64	83	46
31	α Centauri	14 32	−60	− 1	·53	17·70	79	88	43
32	Σ 1879	14 41	+10	+57	·65	0·84	64	87	36
33	ξ Boötis	14 47	+20	+61	·59	5·33	51	81	35
34	η Cor. Bor.	15 19	+31	+56	·27	0·92	52	88	30
35	μ^2 Boötis	15 21	+38	+54	·54	1·27	44	77	11
36	OΣ 298	15 32	+40	+51	·58	0·80	61	83	25
37	γ Cor. Bor.	15 39	+27	+50	·42	0·73	84	79	67
38	ξ Scorpii	15 59	−11	+29	·77	0·70	72	77	50
39	σ Cor. Bor.	16 11	+34	+45	·54	3·82	47	90	18
40	λ Ophiuchi	16 26	+ 2	+30	·68	0·99	30	61	46
41	ζ Herculis	16 38	+32	+39	·56	1·40	50	85	24
42	De 15	16 41	+44	+40	·36	0·77	75	81	44
43	Σ 2107	16 48	+29	+38	·48	0·73	14	67	38
44	β 416	17 12	−35	+ 1	·51	1·22	37	86	72
45	Σ 2173	17 25	− 1	+17	·20	1·14	81	61	54
46	μ^1 Herculis	17 43	+28	+25	·22	1·39	64	83	48
47	τ Ophiuchi	17 58	− 8	+ 7	·59	1·25	58	72	50
48	70 Ophiuchi	18 0	+ 3	+10	·50	4·55	58	88	81
49	99 Herculis	18 3	+31	+21	·78	1·01	0	68	68
50	ζ Sagittarii	18 56	−30	−16	·28	0·69	67	60	45

TABLE I.—*continued.*

No.	Name.	R.A.	Dec.	Gal. Lat.	e	a	i	Γ	Γ′
		h. m.	°	°		″	°	°	°
51	γ Cor. Austr.	19 0	−37	−19	·42	2·45	34	87	53
52	Σ 2525	19 23	+27	+ 4	·95	1·41	57	38	28
53	OΣ 400	20 7	+47	+10	·40	0·57	69	83	73
54	β Delphini	20 33	+14	−17	·37	0·67	61	54	31
55	4 Aquarii	20 46	− 6	−30	·51	0·73	73	61	30
56	δ Equulei	21 10	+10	−27	·36	0·31	77	42	21
57	τ Cygni	21 11	+38	− 8	·37	1·16	47	75	63
58	κ Pegasi	21 40	+25	−22	·49	0·42	81	74	68
59	85 Pegasi	23 57	+27	−35	·39	0·89	56	80	66

3. In the last two columns of the above table, under the notation Γ and Γ′ adopted by Dr See, are given the two possible inclinations of the orbital planes to the plane of the Galaxy. This ambiguity has hitherto somewhat embarrassed the discussion of the distribution of the inclinations in space, and we shall presently return to the consideration of it. But first it may be remarked that it need not trouble us if we adopt the method used in the case of variable stars: for we are at least as well off in dealing with double-star orbits as in dealing with variable stars. We know the inclination of the plane to the line of sight, though we do not know on which side it lies. In the case of the variables, we similarly suppose that we have indications of the inclination of the equator (or of the axis of rotation) to the line of sight, but as regards its orientation round the line of sight we are quite ignorant—our alternatives are infinite in number instead of being two only. Hence we can at any rate apply to the double-star orbits the same test as to the variables; and we proceed to do this in the first instance.

4. On p. 351 of the present volume of *Mon. Not.* is given a list of twenty stars with large values of α, the suggestion being that these are rotating suns which present their polar regions to us, their equators lying at right angles to the line of sight. The analogy in the case of a double star is an orbit for which i is small, so that the apparent orbit is well open. The values of i are given in the 8th column of the above table, and we can accordingly pick out the small values of i; or, what is more complete, arrange the whole series according to the value of i as in Table II.

TABLE II.

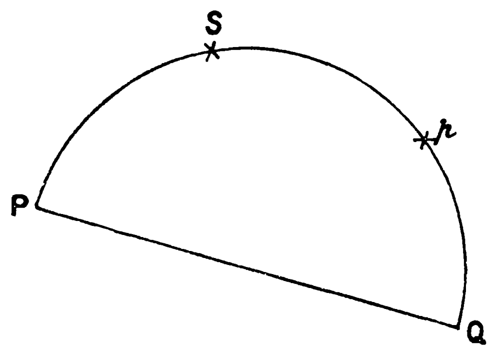
Orbits in Order of Inclination to Plane of Projection.

i	Star's No	Gal. Lat.	i	Star's No.	Gal. Lat.	i	Star's No.	Gal. Lat.
0°	49	+21°	50°	41	+39°	69°	53	+10°
11	15	+26	51	22	+68	69	11	−37
14	43	+38	51	33	+61	71	28	+77
28	12	−20	52	34	+56	72	2	+16
30	40	+30	56	59	−35	72	38	+29
30	19	+48	56	20	+70	73	55	−30
33	26	+62	57	52	+ 4	74	10	−19
34	51	−19	58	47	+ 7	74	7	−57
36	16	+38	58	24	+86	75	17	+44
36	29	+75	58	48	+10	75	42	+40
37	44	+ 1	61	36	+53	77	4	−87
43	5	− 6	61	54	−17	77	8	−19
44	1	− 4	62	25	+14	77	56	−27
44	35	+54	63	18	+40	78	14	+ 8
45	6	−40	64	30	+70	79	31	− 1
45	13	− 8	64	32	+57	81	45	+17
47	39	+45	64	46	+25	81	58	−22
47	57	− 8	66	9	−13	84	37	+50
48	3	−67	66	21	+64	90	27	+82
49	23	+53	67	50	−16			

5. It will be seen from Table II. that the orbits with small values of i do show some tendency to lie near the Galaxy. There are exceptions such as No. 29 which, with an inclination of 36°, has a Galactic Latitude of 75°. This star is 25 Canum Ven. It has not yet completed a revolution (period 220 years) or been observed near apastron, while the orbit is so eccentric that it cannot be observed near periastron; consequently the elements are somewhat uncertain: possibly further knowledge will sensibly increase the value of i and the eccentricity, which seem (from inspection of the three orbits computed) to go together. But to enter upon criticism of orbits computed would take us too far: it is sufficient to remark here that there may be considerable uncertainty in the determination of i, as a few examples will illustrate. Thus in the case of γ Virginis (No. 26) there will be found on p. 339 of *Mem. R.A.S.*, vol. lvi., a list of 22 orbits with values of i ranging from 0° to 68°. They are not all of equal merit, but all of them are *bonâ fide* attempts to satisfy the observations. Again, for λ Ophiuchi the value 58° rather than 30° has been assigned to i; for ξ Scorpii the value of i has recently been changed from 72° to 29°; for ξ Boötis

the values range from 35° to 80°, and so on. Of course this uncertainty cuts both ways, and cannot be used to bring the above table into better accord with a hypothesis; but it is to be remembered as a possible explanation of discrepancies.

6. Before proceeding to analyse the columns Γ and Γ′, it is desirable to consider the general effect of the ambiguity. Let us represent each orbit by its pole, *i.e.* the point in which a line perpendicular to it cuts the celestial sphere. For every real pole P there is a corresponding spurious pole *p* on the opposite side of the



star S, and equidistant from it. We cannot tell without independent evidence such as may ultimately be afforded by the spectroscope,* which is the right one. But we can study this question:— Suppose P tends to lie near the Milky Way for all positions of S, will *p* have a tendency to lie in any particular region or regions? and, if so, which?

7. A preliminary question must first be asked with regard to the distribution of the star S. Does it appear from the above list that double stars congregate towards the Milky Way? The numbers for every 10° of Galactic Latitude are as follows:—

Table III.

Distribution of the Stars of Table I. in Galactic Latitude.

Galactic Lat.	Observed No. of Stars.	Calcd.	O – C.
0° – 9°	9	10	– 1
10 – 19	13	10	+ 3
20 – 29	6	9	– 3
30 – 39	7	9	– 2
40 – 49	6	7	– 1
50 – 59	7	6	+ 1
60 – 69	4	4	0
70 – 90	7	4	+ 3
Total	59	59	0

* It is strange to think that we do not yet know which is the real orbit even of α Centauri. Could not some spectroscopic observer determine this for us? There are also η Cassiopeiæ, *p* Eridani, and others.

In the column "Calc." the theoretical distribution of 59 stars, uniformly scattered over the sphere, is given. The column O − C shows that the actual stars are in defect near the Galaxy and in excess near its poles. But the differences are small and the scattering may be taken as nearly uniform.

8. Returning now to the figure, let us suppose in the first instance that, the pole P being given and remaining therefore fixed, the star S is scattered at random over the sphere. What will be the consequent distribution of the spurious pole p? One feature of it is especially noteworthy. The most common value of PS will be 90°, since the equator of P is the largest circle with centre P. Now all the stars which lie in the equator of P have corresponding poles at 180° from P (since $Pp = 2PS$): that is, in Q, the point opposite to P on the sphere. There is thus a great concentration of spurious poles in and near this point Q. Similarly the point Q will, as a real pole, give rise to a concentration of spurious poles near P.

9. It is easy to write down the symbolical expressions for the density of the spurious poles, but it will be more directly useful to us to work with numbers. Starting with the numbers of stars in each zone of 10° outwards from P up to PS = 90°, the spurious poles of these will fall in zones of 20°, up to $Pp = 180°$. The stars in the hemisphere for which PS > 90° will be referred to pole Q, and will give a series of numbers in the reverse order; and adding together the two, we get a distribution of spurious poles (corresponding to a uniform scattering of stars and a given pair of real poles PQ) as follows:—

TABLE IV.

PS.	Number of Stars: see Table III.	Pp.	Number of Spurious Poles.	Uniform Dist.	Excess over Uniformity.
° °		° °			
0–10	1	0– 20	1 + 10 = 11	3	+ 8
10–20	3	20– 40	3 + 10 = 13	8	+ 5
20–30	4	40– 60	4 + 9 = 13	12	+ 1
30–40	6	60– 80	6 + 9 = 15	14	+ 1
40–50	7	80–100	7 + 7 = 14	15	− 1
50–60	9	100–120	9 + 6 = 15	14	+ 1
60–70	9	120–140	9 + 4 = 13	12	+ 1
70–80	10	140–160	10 + 3 = 13	8	+ 5
80–90	10	160–180	10 + 1 = 11	3	+ 8
Total			118	89	29

10. Thus for uniformly scattered stars we have, out of 118 spurious poles, 89 of them scattered uniformly over the sphere and 29 tending to collect round the real poles, the density near the poles being quite considerable.

11. If then the 59 real poles lie near the Milky Way, while the stars are scattered uniformly over the sphere, we shall have

44 of the spurious poles scattered uniformly over the sphere and 15 tending to coincide with the real poles near the Milky Way.

Now we may proceed in the following manner. We may assume in the first instance that the spurious poles are all uniformly scattered, and then deduce the distribution of the real poles. If any peculiarity of distribution is found, we must then reduce it by some 20 per cent. to allow for the spurious poles.

13. Let us therefore consider the distribution of real and spurious poles together, and then make allowance for the spurious poles on the principle of uniform scattering; this is done in Table V.

TABLE V.

Values of Γ or Γ′.	Observed Total Number.	Subtract Uniform Distribution of Γ′.	Γ alone.	Observed Excess over Unif. Distr.
0°–19°	7	4	3	− 1
20–29	6	4	2	− 2
30–39	11	6	5	− 1
40–49	12	7	5	− 2
50–59	14	8½	5½	− 3
60–69	28	9½	18½	+ 9
70–79	13	10	3	− 7
80–90	27	10	17	+ 7
Total	118	59	59	0

In the second column are given the number of cases (from Table I.) where either Γ or Γ′ lies within the limits indicated in the first column. In the third, an allowance is made for Γ′ on the hypothesis of uniform distribution. The remaining numbers in the fourth column should represent the distribution of the real poles: and in the fifth column this is compared with a random or uniform distribution. It will be seen that an excess towards the Galaxy exists, though it is not very large. Still it is large enough to make it impossible, for instance, to maintain the contrary proposition—that the orbits of double stars tend to lie parallel to the Galaxy.

14. The above result is obtained from the whole list of orbits, without any selection. But it is noteworthy that if we limit the inquiry to the larger orbits, the tendency of the poles toward the Galaxy is more marked. It seems worth while to put on record the result, for example, of limiting the material to orbits of which the semi-major axis exceeds 0″·50. Recurring to Table I., there are 48 of these orbits: and for them we should replace Table V. by Table VI. as follows :—

TABLE VI.

Larger Orbits only.

Values of Γ or Γ′.	Observed Total Number.	Subtract Uniform Distribution of Γ′.	Γ alone.	Observed Excess over Unif. Distr.
0°–19°	6	3	3	0
20–29	4	3	1	–2
30–39	8	5	3	–2
40–49	8	6	2	–4
50–59	13	7	6	–1
60–69	22	8	14	+6
70–79	11	8	3	–5
80–90	24	8	16	+8
Total	96	48	48	0

15. The exclusion of the smaller orbits is reasonable since there is systematic error affecting observations of very close doubles. The following figures will illustrate the nature of this error. In Dr T. J. J. See's *Evolution of Stellar Systems*, tables are given showing the residuals ($\rho_0 - \rho_c$) of the observed distances over the calculated. These were collected according to the value of ρ_c in all cases where ρ_c falls below 0″·60 after the year 1870. [The measurement of very small distances has become more feasible in recent years, and it was thought better to limit the inquiry to modern observations.] The following table gives the results for all orbits represented in all three of the groups selected:—

TABLE VII.

Evolution of Stellar Systems. $\rho_0 - \rho_c$ *for small values of* ρ_c.

Star.	ρ_c=0″·60 to 0″·45.		0″·44 to 0″·25.		Under 0″·25.	
	$\rho_0-\rho_c$. (Sum).	No. Obs.	$\rho_0-\rho_c$. (Sum).	No. Obs.	$\rho_0-\rho_c$. (Sum).	No. Obs.
γ Androm.	+ ″·02	6	+ ″·10	4	+ ″·14	7
9 Argus	– ·01	3	+ ·03	7	+ ·06	1
Σ 3121	– ·20	7	+ ·21	11	+ ·08	4
42 Com. Ber.	+ ·21	8	+ ·25	8	– ·02	3
OΣ 298	+ ·09	3	– ·11	10	+ ·14	2
γ Cor. Bor.	– ·63	6	– ·11	3	+ ·60	2
Σ 2173	– ·07	3	– ·10	4	+ ·01	2
β Delphini	– ·10	4	– ·04	9	+ ·21	4
δ Equulei	– ·57	4	– ·20	6	+ ·10	3
Sums	–1″·26	44	+″·03	62	+1″·32	28
Means	–0″·029	...	+0″·000	...	+0″·047	...

16. It thus appears that double-star observers are liable to measure very small distances too large. There is nothing unreasonable or even unlikely in this, and the above figures may even underestimate the amount, since some concession to the error is probably made in determining the orbit. Now, if the existence of such an error is admitted, the elements of the small orbits will require systematic revision. It is not easy to say what the general effect on the inclinations would be, and such an inquiry cannot in any case be undertaken here. But it seems desirable to suspend judgment at present, with regard to any distribution of orbital inclinations, until we know more of the possible systematic errors of the smaller orbits.

17. If, now, we further limit the material to orbits of moderate eccentricity, the figures become still more striking. Excluding from the 48 above, 22 orbits for which e exceeds 0·51, we get—

TABLE VIII.

Values of Γ or Γ′.	Observed Total Number.	Subtract for Γ′.	Γ alone.	Excess over Uniform.
0°–19°	2	2	0	−2
20–29	0	2	(−2)	−4
30–39	4	2	2	0
40–49	4	3	1	−2
50–59	8	4	4	0
60–69	15	4	11	+7
70–79	5	4	1	−3
80–90	14	5	9	+4
Total	52	26	26	0

18. The limit $e = 0{\cdot}51$ was selected in order to make the excess near the Galaxy as striking as possible. The general effect of including other orbits can be seen from the following figures for the 48 orbits :—

Value of e . . .	< ·40	·40 to ·51	·52 to ·59	·60 to ·79	> ·80	Total
Values of Γ and Γ′ < 60°	12	6	8	7	6	39
,, > 60°	18	16	10	11	2	57

or if we assume uniform distribution of Γ′ the numbers would be

Value of e . .	< ·40	·40 to ·51	·52 to ·59	·60 to ·79	·80 and over
Values of Γ < 60°	4½	½	3½	2½	4
,, Γ > 60°	10½	10½	5½	6½	0

The difference between the results for large values of e and those for small may be due either to observational or to physical causes. When the stars approach very close together, observations are difficult and likely to be affected by systematic error, so that the determinations of inclination will be affected; and on the

other hand, just as in the solar system the planetary orbits are at the same time of small eccentricity and systematically disposed near one plane (which is at a high inclination to the Galaxy), while comets have orbits of high eccentricity with planes in miscellaneous orientations,—so there may be a real difference between double star orbits of low and of high eccentricity.

19. It seems worth while to form a new table corresponding to Table II. for the 26 orbits retained in Table VIII.

TABLE IX.

Similar to Table II., but excluding orbits of small size ($a < 0''\cdot5$) *and high eccentricity* ($e > 0\cdot51$).

i	Star's No.	Gal. Lat.	i	Star's No.	Gal. Lat.	i	Star's No.	Gal. Lat.
11	15	+26°	56	20	+70°	75	17	+44°
14	43	+38	58	48	+10	75	42	+40
34	51	−19	61	54	−17	77	4	−87
37	44	+1	64	46	+25	81	45	+17
43	5	−6	66	9	−13	84	37	+50
44	1	−4	67	50	−16	90	27	+82
47	57	−8	69	53	+10			
49	23	+53	69	11	−37			
52	34	+56	72	2	+16			
56	59	−35	73	55	−30			

Ancient Eclipses. By P. H. Cowell, F.R.S.

As my whole argument from the ancient lunar eclipses is—"If I have placed a wrong interpretation upon the records of solar eclipses, how is it that the results so obtained agree so well with the lunar eclipses?" I am, of course, perfectly satisfied with such sentences as these in Mr Nevill's recent papers:—

"During past years in my researches I have repeatedly found evidence of an unexplained apparent secular acceleration in the motion of the Moon's argument of latitude . . . ." (*M.N.*, lxvii. p. 17).

"These early eclipse observations . . . . are certainly not inconsistent with Mr Cowell's conclusion that the Moon's argument of latitude requires an increased secular acceleration" (p. 13).

In my view the lunar eclipses by themselves do not amount to a proof, and I do not ask Mr Nevill to say more than he has said.

Mr Nevill, however, attaches more weight than I do to the times of lunar eclipses. From the times the mean elongation is